Elements of Design That Influence Long PCCP Life

Michael I. Darter

Emeritus Professor, University of Illinois

Principal Engineer, ERES Division of ARA, Inc.

Caltrans/FHWA/Western States Chapter

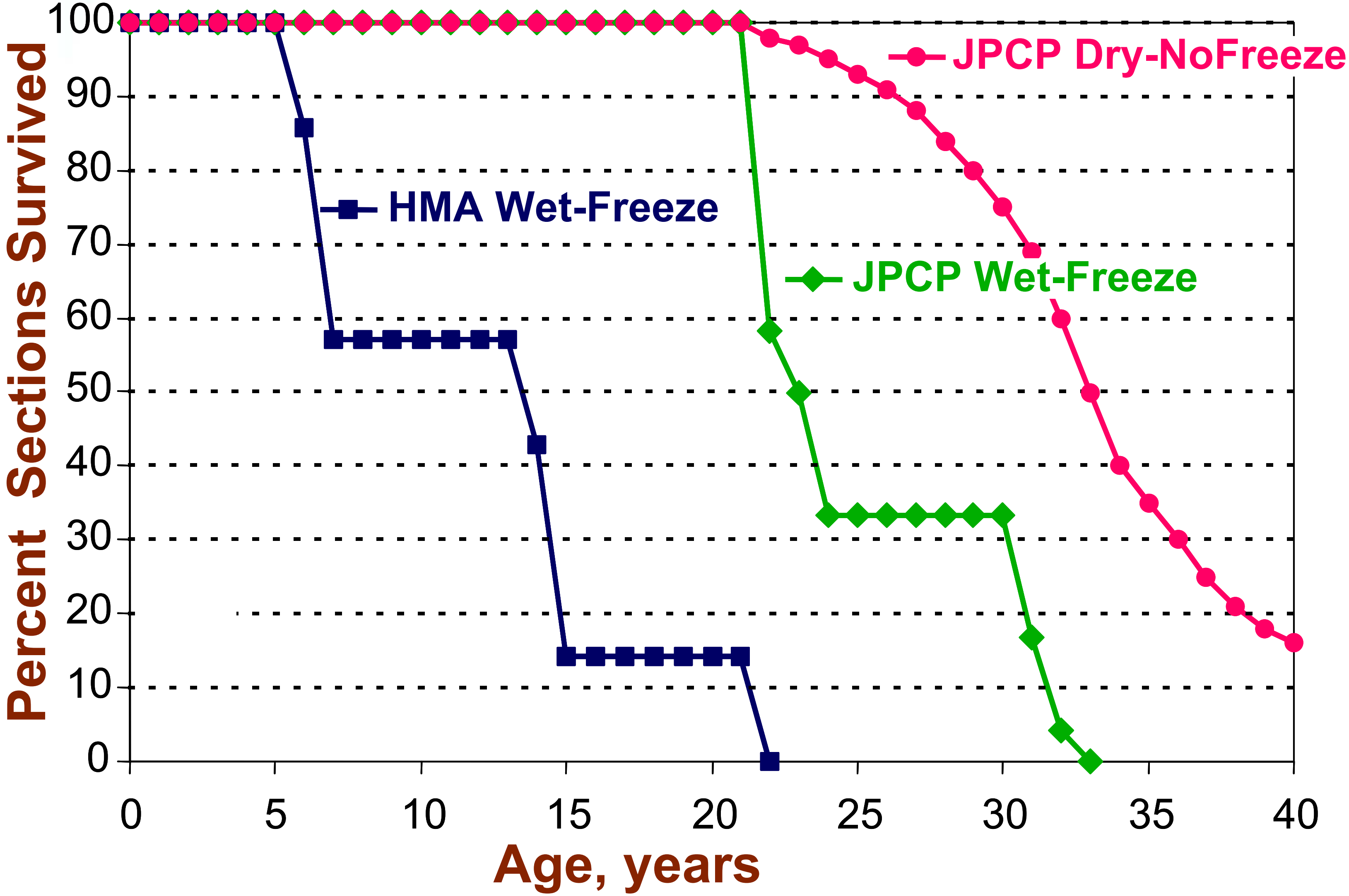
Annual Conference

October 18, 20 and 21, 2004

Achieving Long-Life Concrete Pavements in California

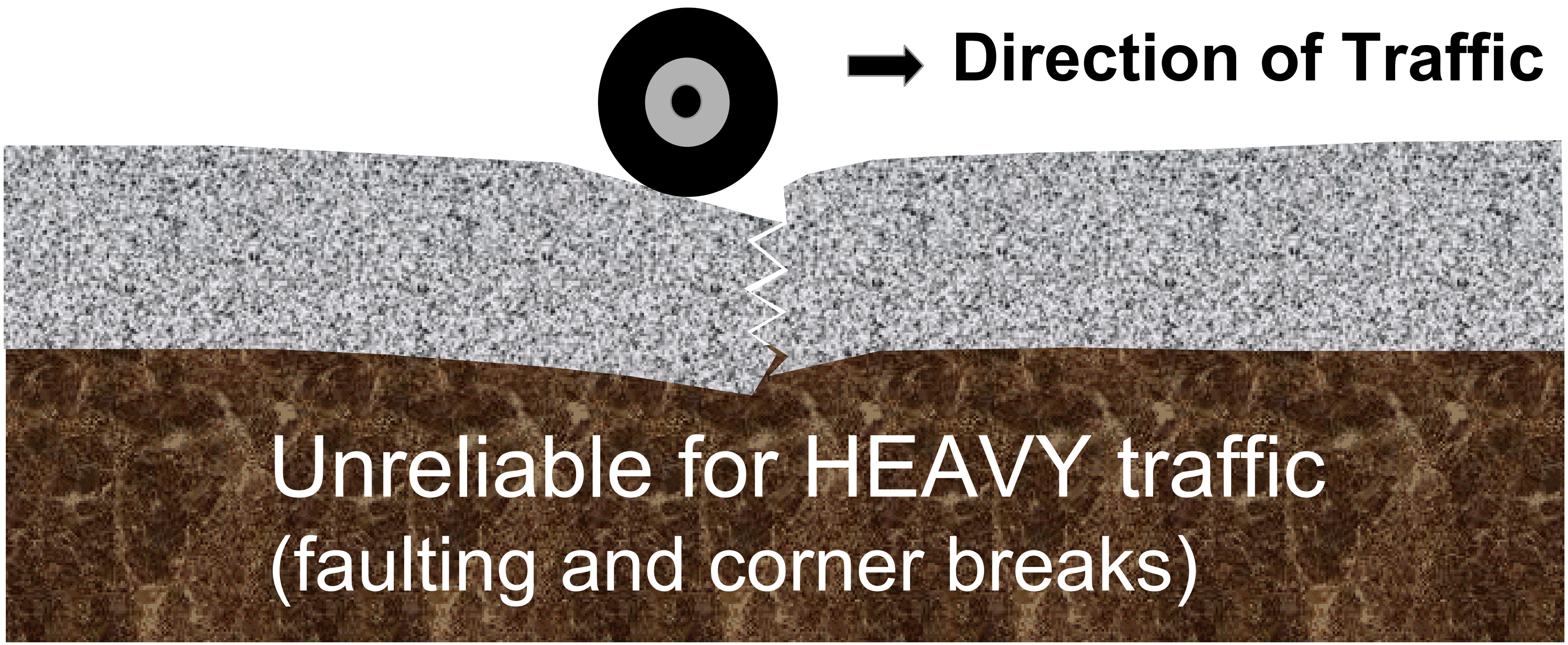
- Four major processes in producing a concrete pavement:
  1. Structural & joint design of the pavement
  2. Concrete materials and mix design
  3. Construction of the pavement
  4. Maintenance
- Long-life: like links in a chain…

The Past: Survival Curves



The Past: Relying on Aggregate Interlock Only

- High deflections and stresses



The Past:

- No dowels
- Built in bathtub
- Erodable base
- **Heavier truck traffic than ever imagined!**

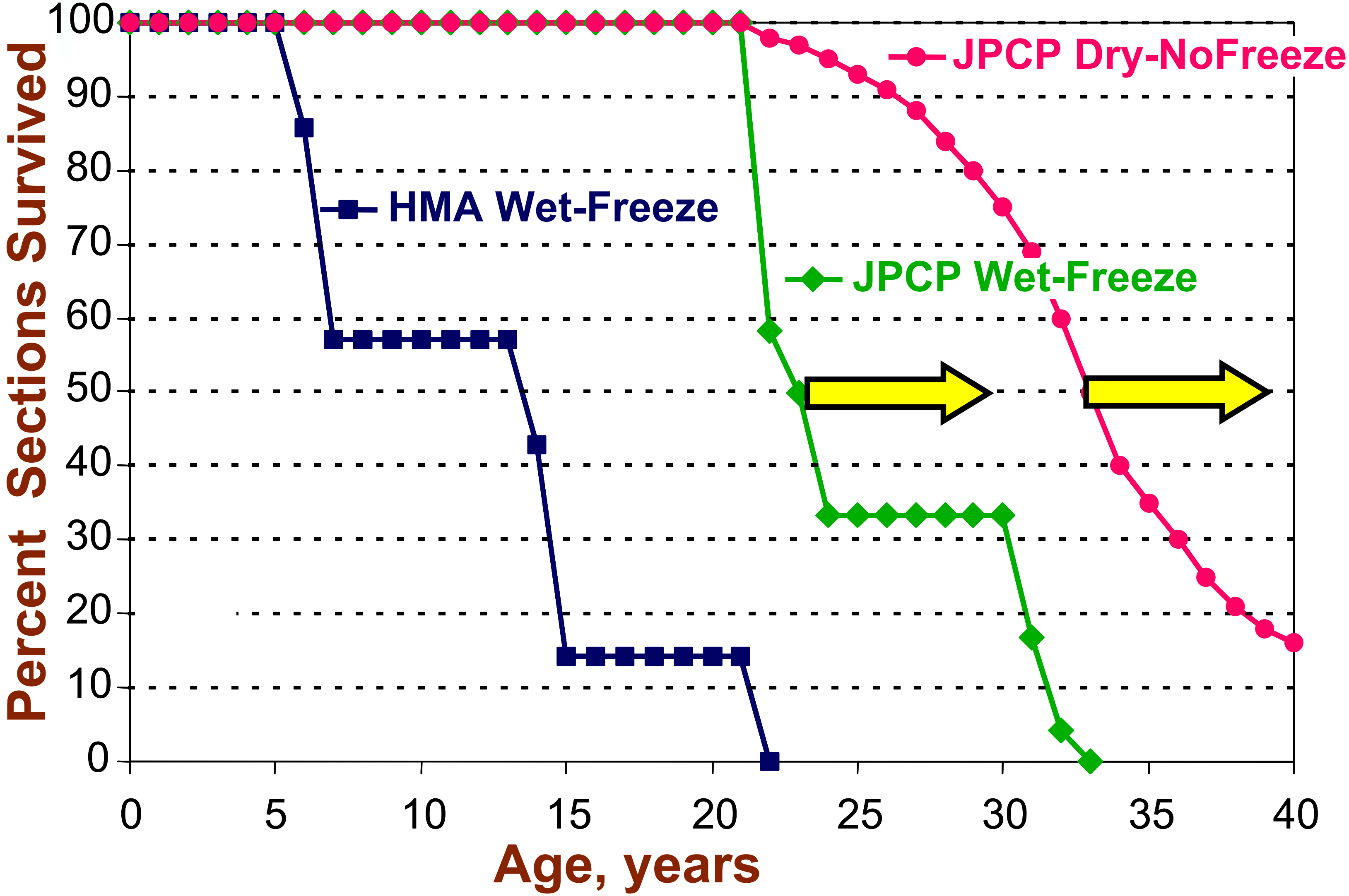
The Past: Too Long Joint Spacing

21 projects in California 1970's construction

- 3.6 to 4.0-m joint spacing
  - ✓Mean 10 percent slabs cracked
- 5.5 to 5.8-m joint spacing
  - ✓Mean 34 percent slabs cracked

The Past: Durability Problems
Alkali-Silica Reaction

The Future: Survival Curves



Current Improved Technology

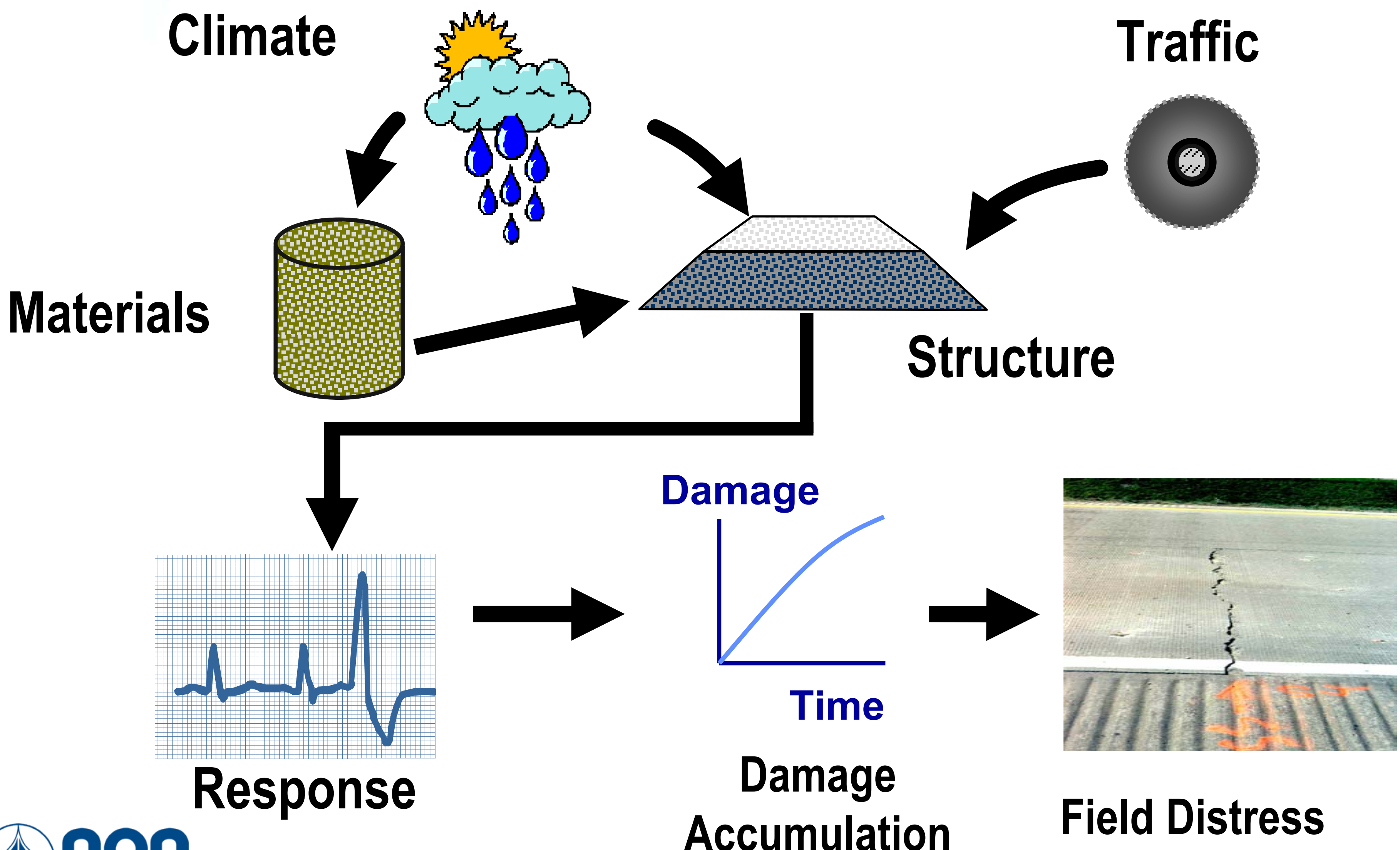
Mechanistic Design

- Several countries including the US has sponsored the development of a new procedures based on engineering principles

AASHTO: NCHRP 1-37A

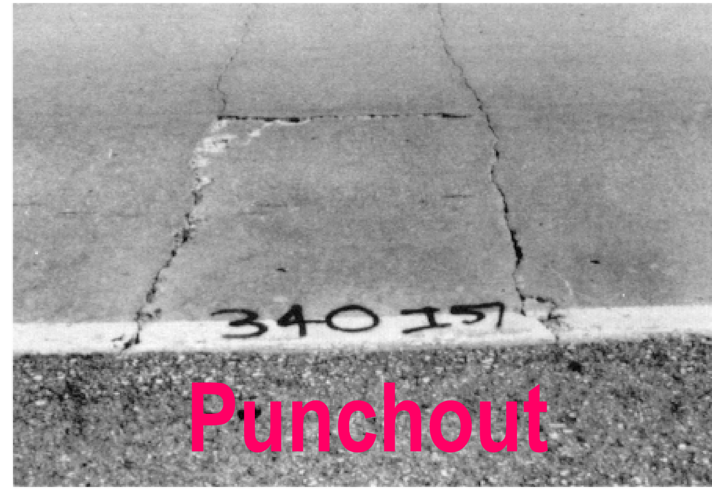
- 6-year (1998-2004) research and development of new concrete pavement design procedure
- Paradigm shift in design of new JPCP & CRCP & Overlays

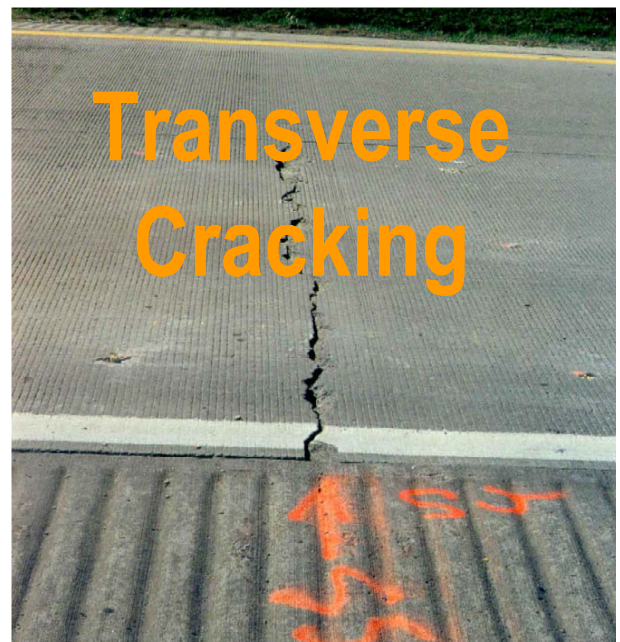
Mechanistic-Empirical Design



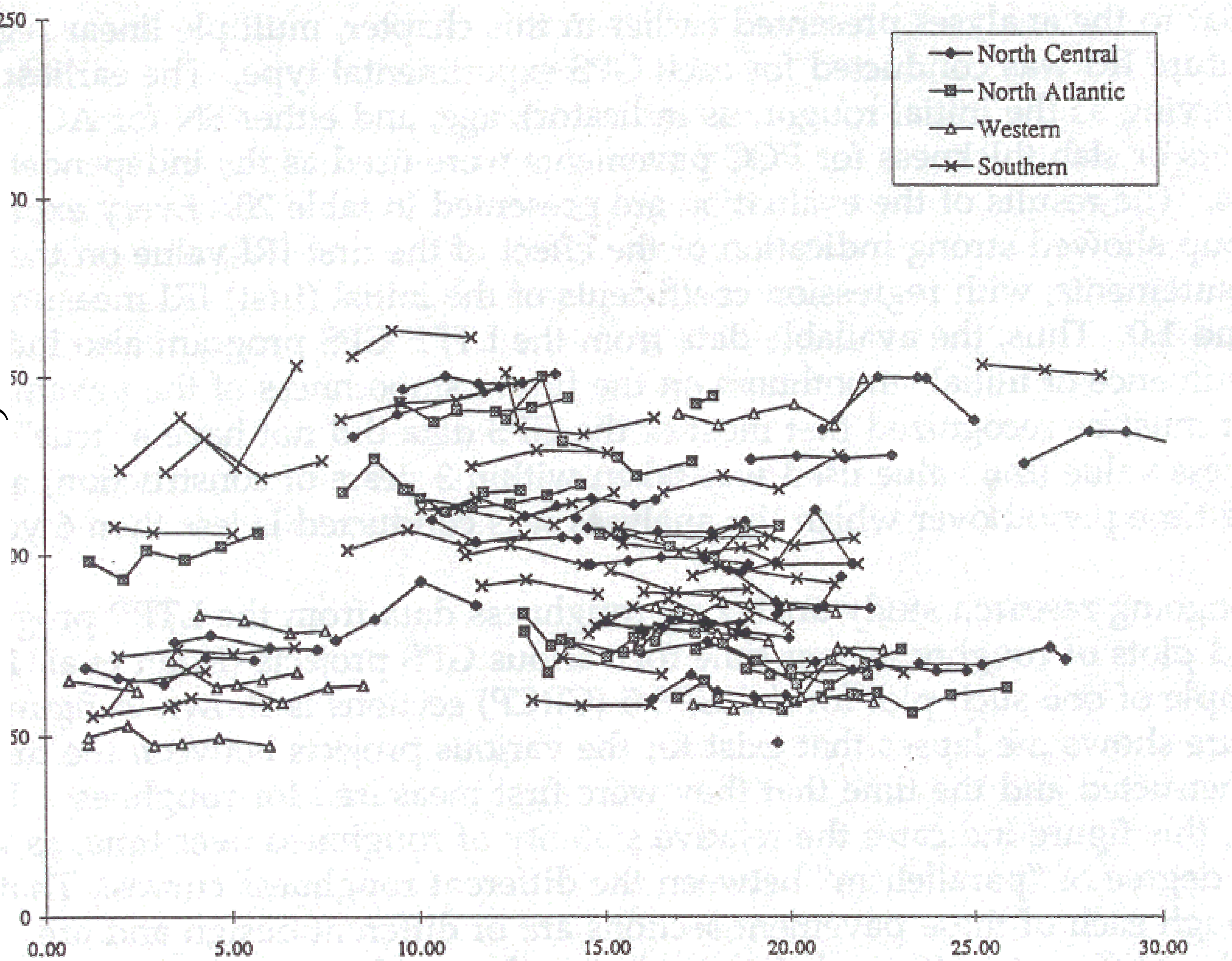
Design Guide Software

Design to Prevent Key Distress





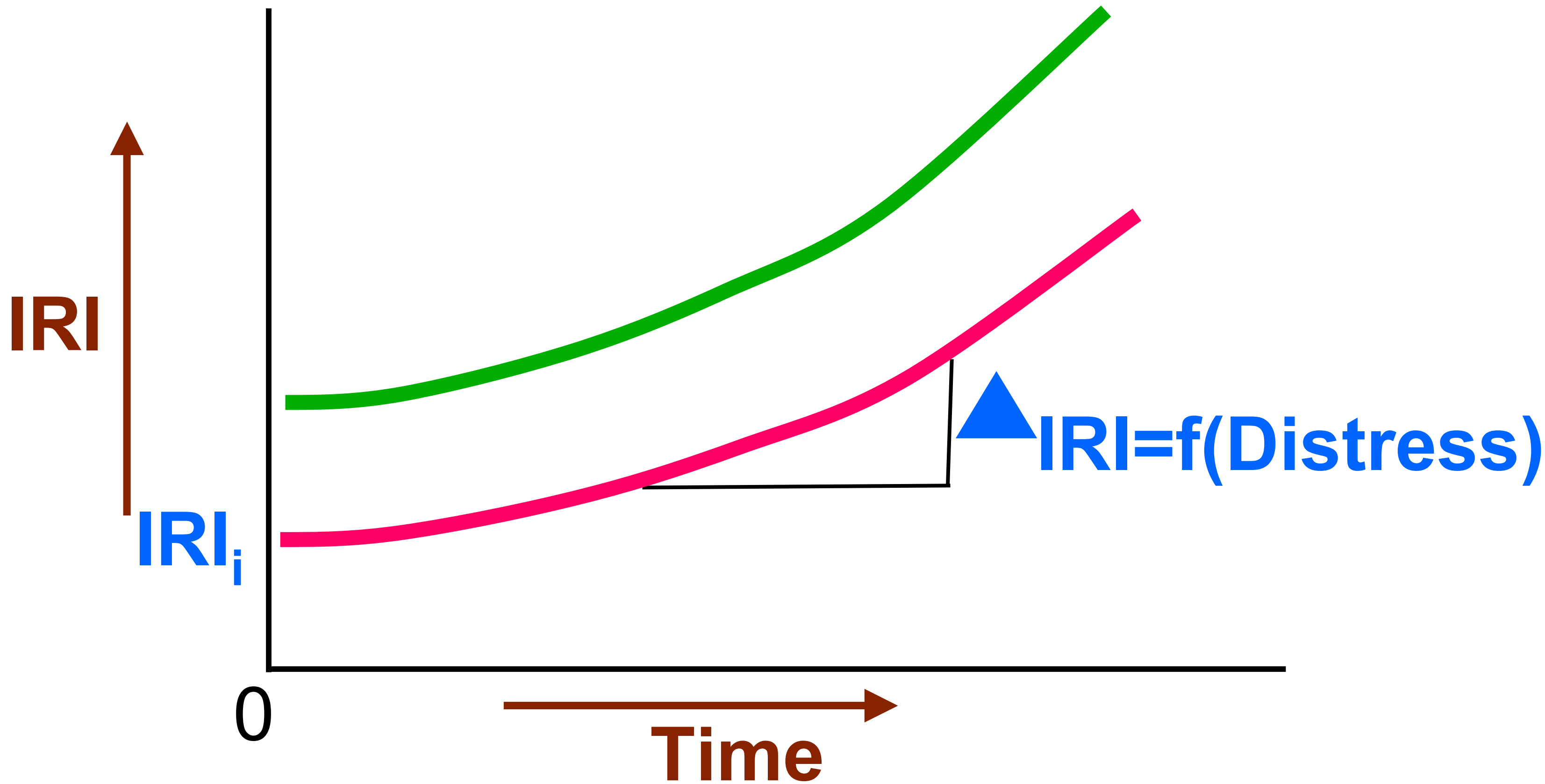
LTPP PCC Smoothness Trends



Mean IRI, in/mi

Age, years

Impact of Construction: Initial Smoothness

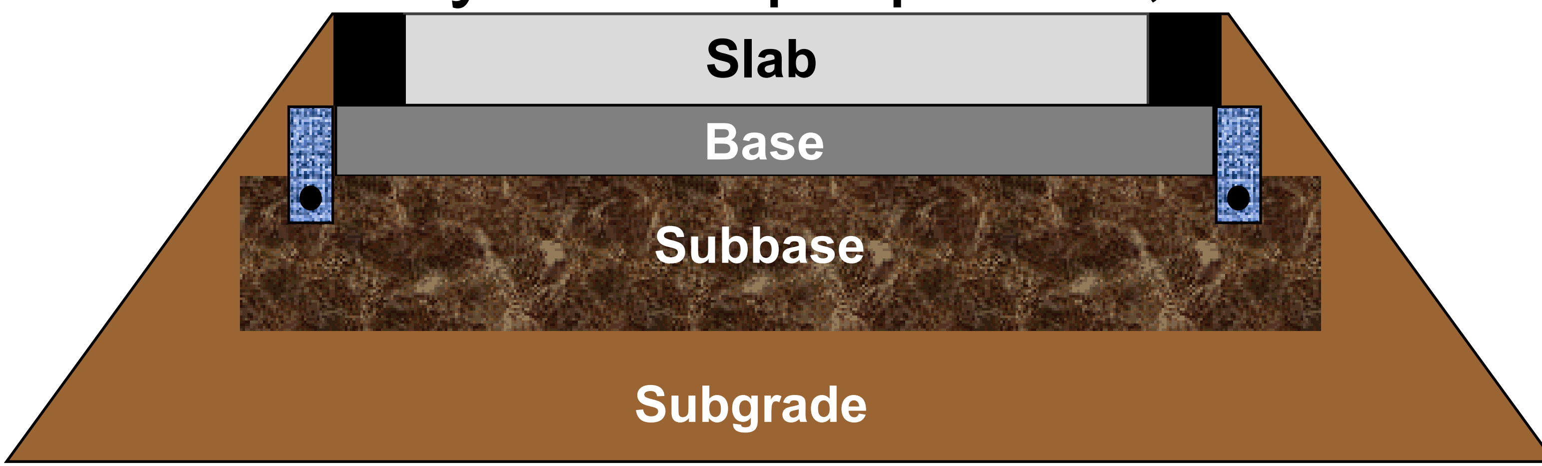


NCHRP 1-31: Effect of Initial Pavement Smoothness on Pavement Life

- Evaluation of historical pavement performance data from 10 States strongly indicated that **initial smoothness** has a **significant effect on pavement life**.
- **Added pavement life is obtained by achieving a higher level of initial smoothness**.
- Two different analyses used to reach this finding:
  - ✓ Smoothness along many projects (mile by mile): smooth sections stay smooth over life.
  - ✓ Pavement survival analysis in Kentucky & Wisconsin.

Materials Characterization

- **For Each Layer:** longitudinal edges, elastic modulus, strength, thickness, thermal & hydraulic properties, others …

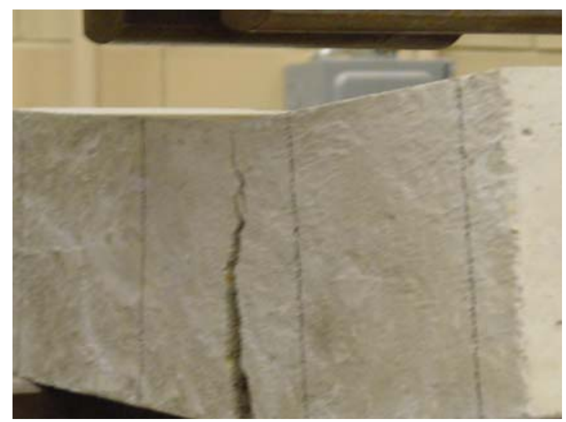


Concrete Slab Characterization

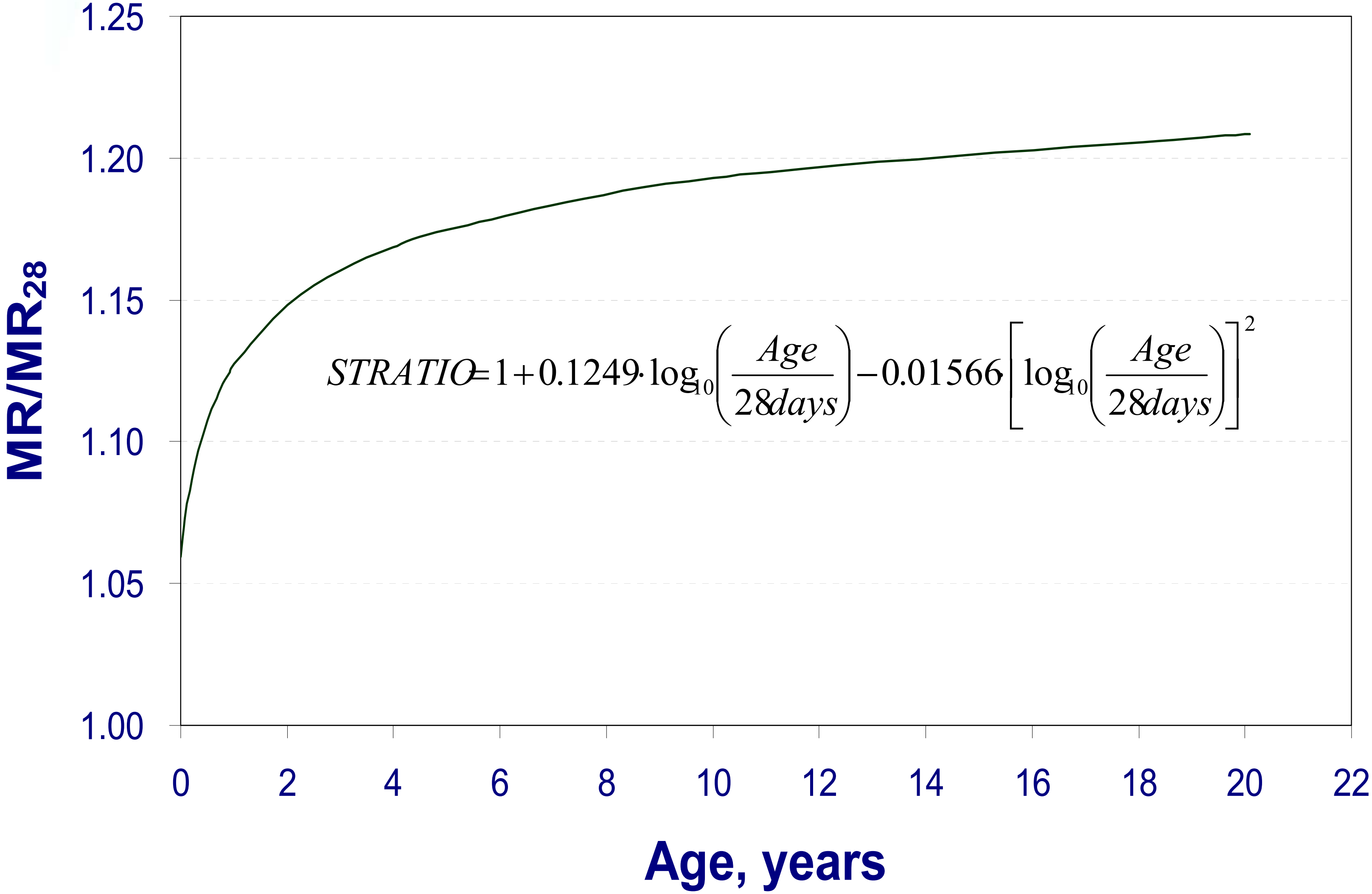
- Flexural strength (over time)
- Modulus of elasticity (over time)
- Coefficient of thermal expansion
- Permanent curl/warp
- Joint spacing
- Slab thickness

Effects of PCC properties on JPCP Performance--Strength

- Cracking: strength < stress
- California flexural strength at 28-days: 667 psi [585-720]
- PCC strength – the higher the better to reduce cracking, but may be associated with:
  - ✓ Higher shrinkage
  - ✓ Higher modulus of elasticity



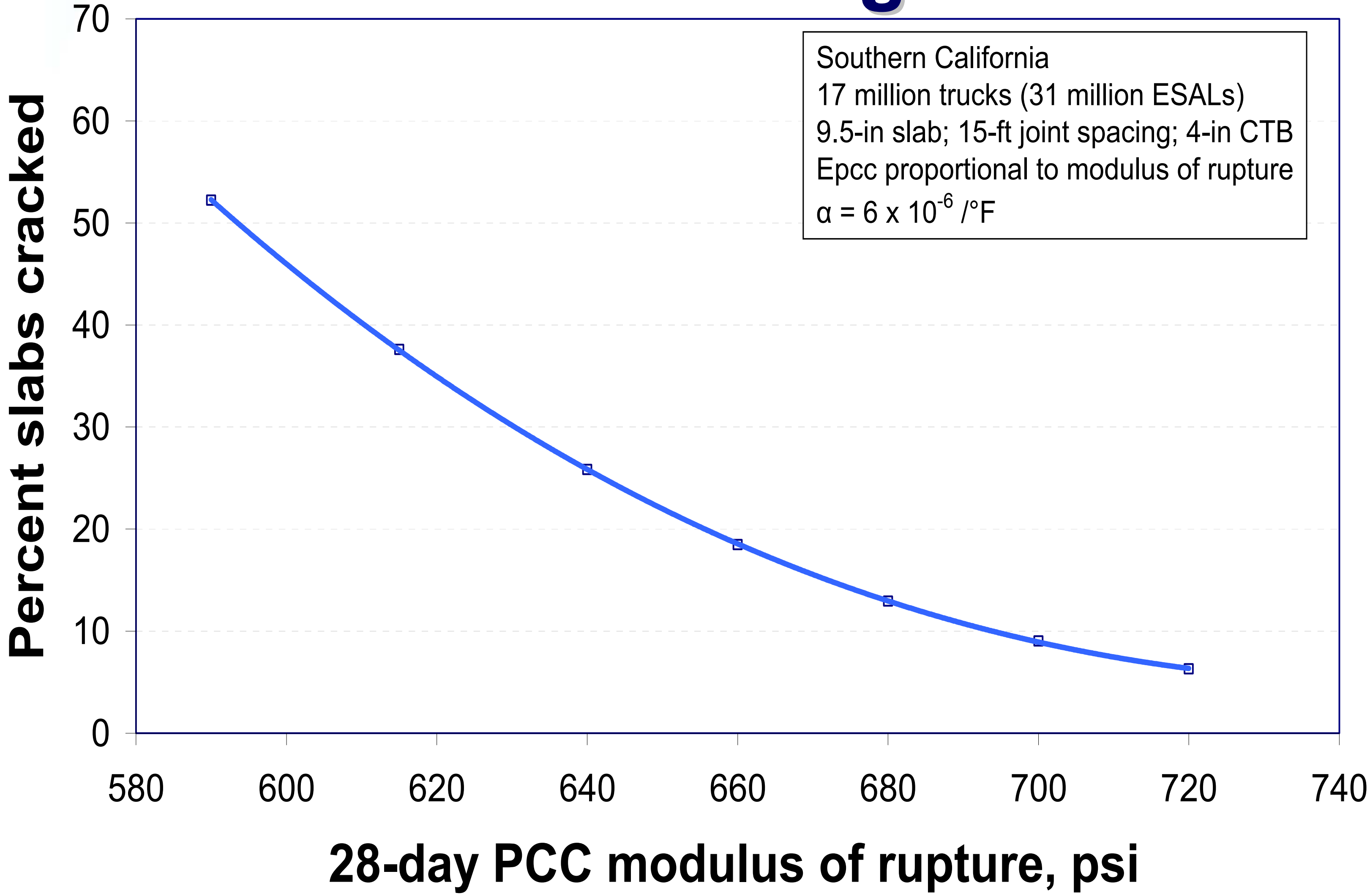
PCC strength gain model



Effects of PCC properties on JPCP Performance—Modulus of Elasticity, Ec

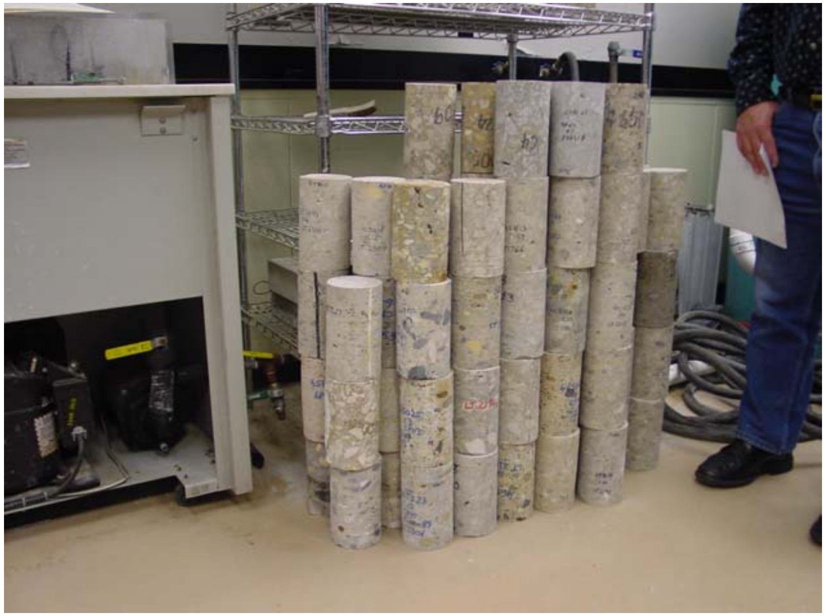
- PCC elastic modulus (Ec) – lower is better!
- Cores from California JPCP showed consistently lower Ec
  - ✓ 3,325,000 psi CA vs 4,800,000 psi nationally

Effects of PCC strength on JPCP cracking



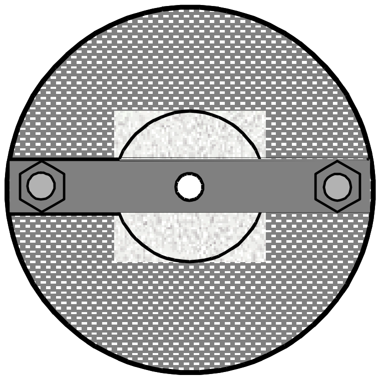
Effects of PCC properties on JPCP—Thermal Coefficient Expansion

- Thermal coefficient – lower is better!
- California PCC ranged from 5.9 to 6.6 with an average of 6.15 E-06 per degree F
- Depends mainly on aggregate type
- Test method - AASHTO TP60-00

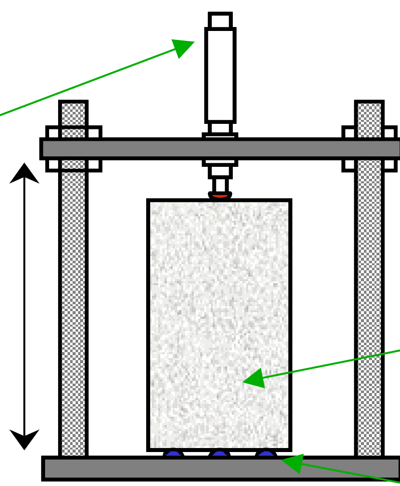


Concrete CTE – Test Apparatus

- Test procedure essentially involves measuring change in length of the test specimen at different temperatures
- Length change is measured after expansion and contraction cycles, i.e., a heating and a cooling cycle

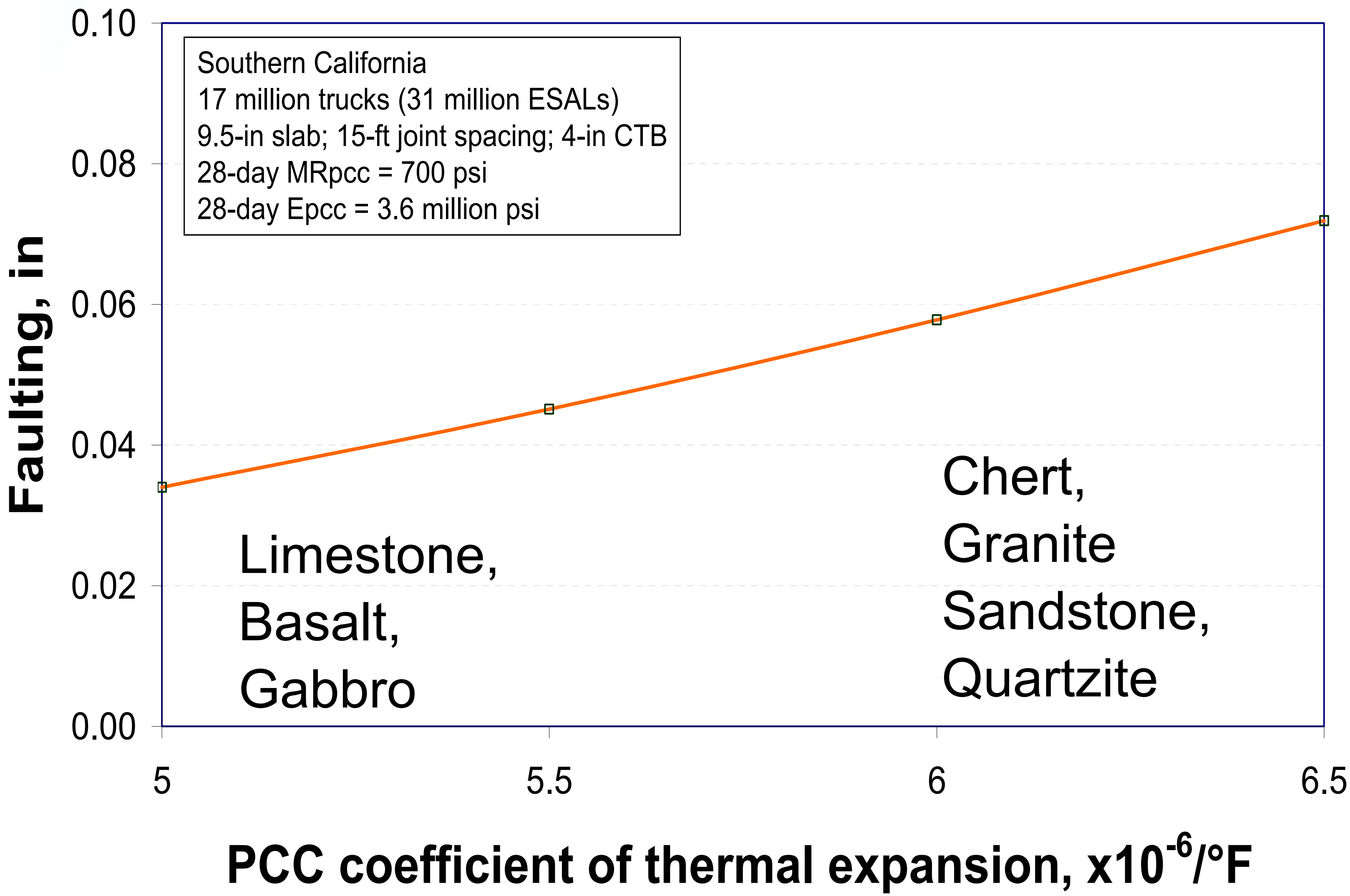


Top View

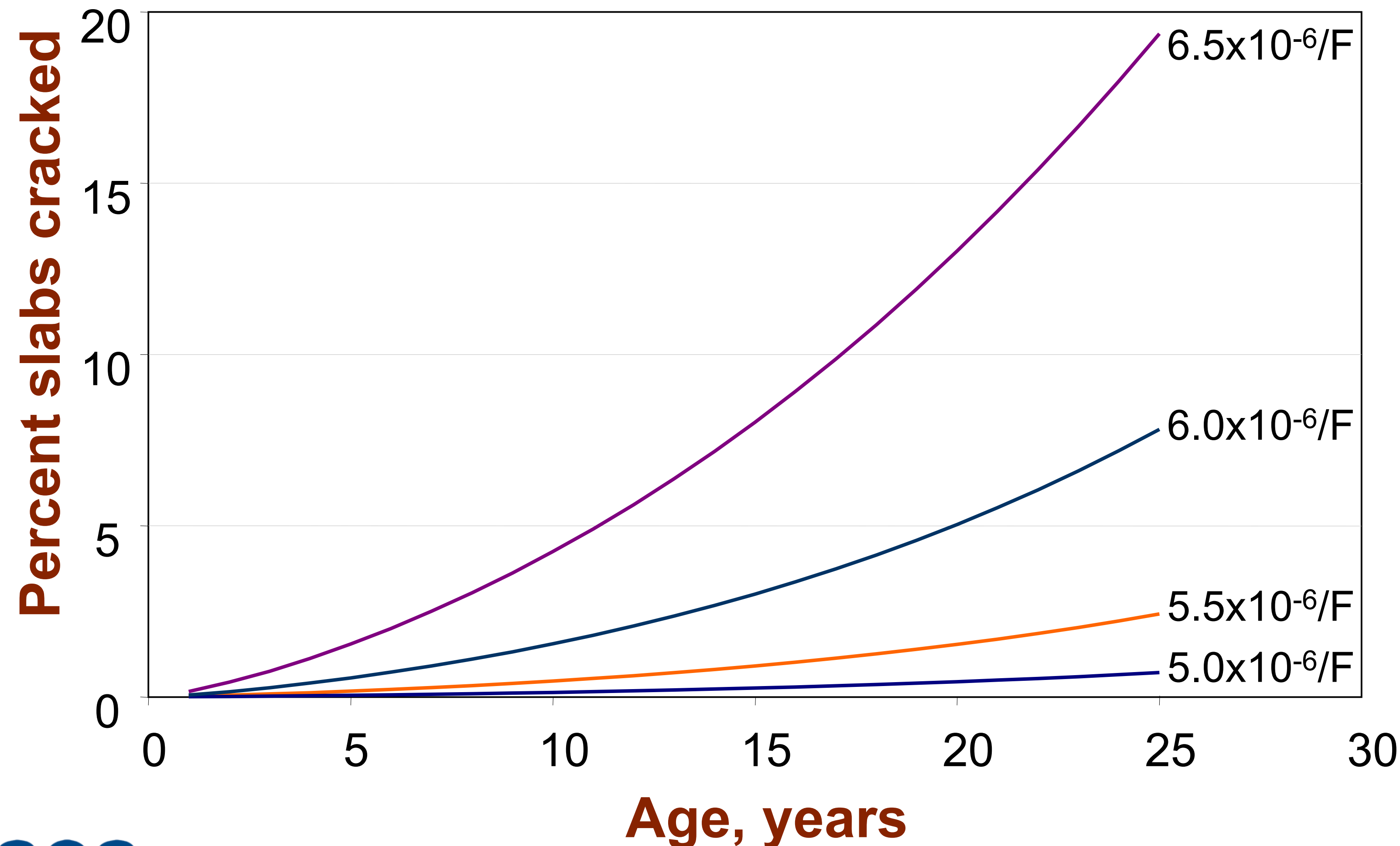


Test Frame

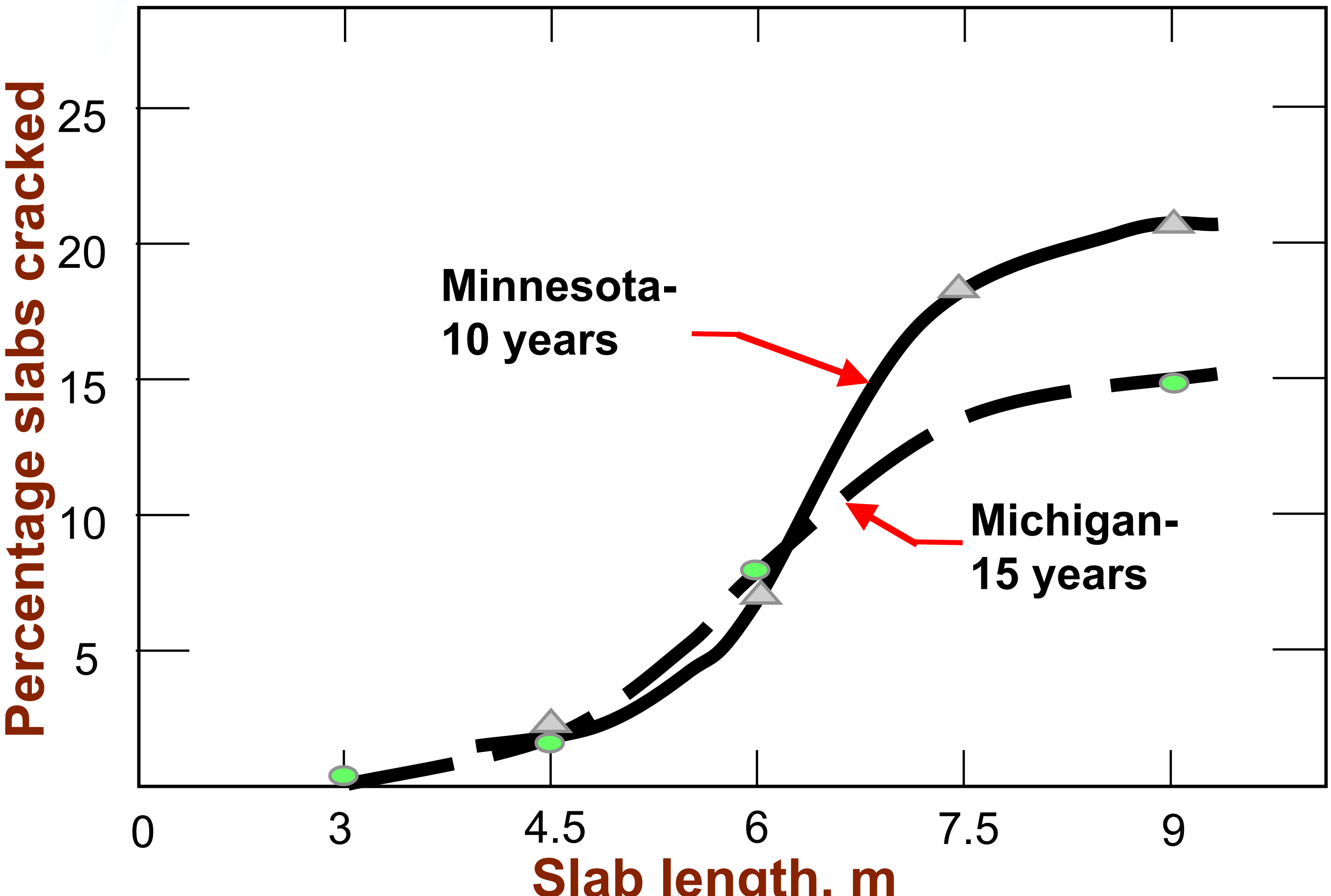
Effects of PCC Thermal Coefficient



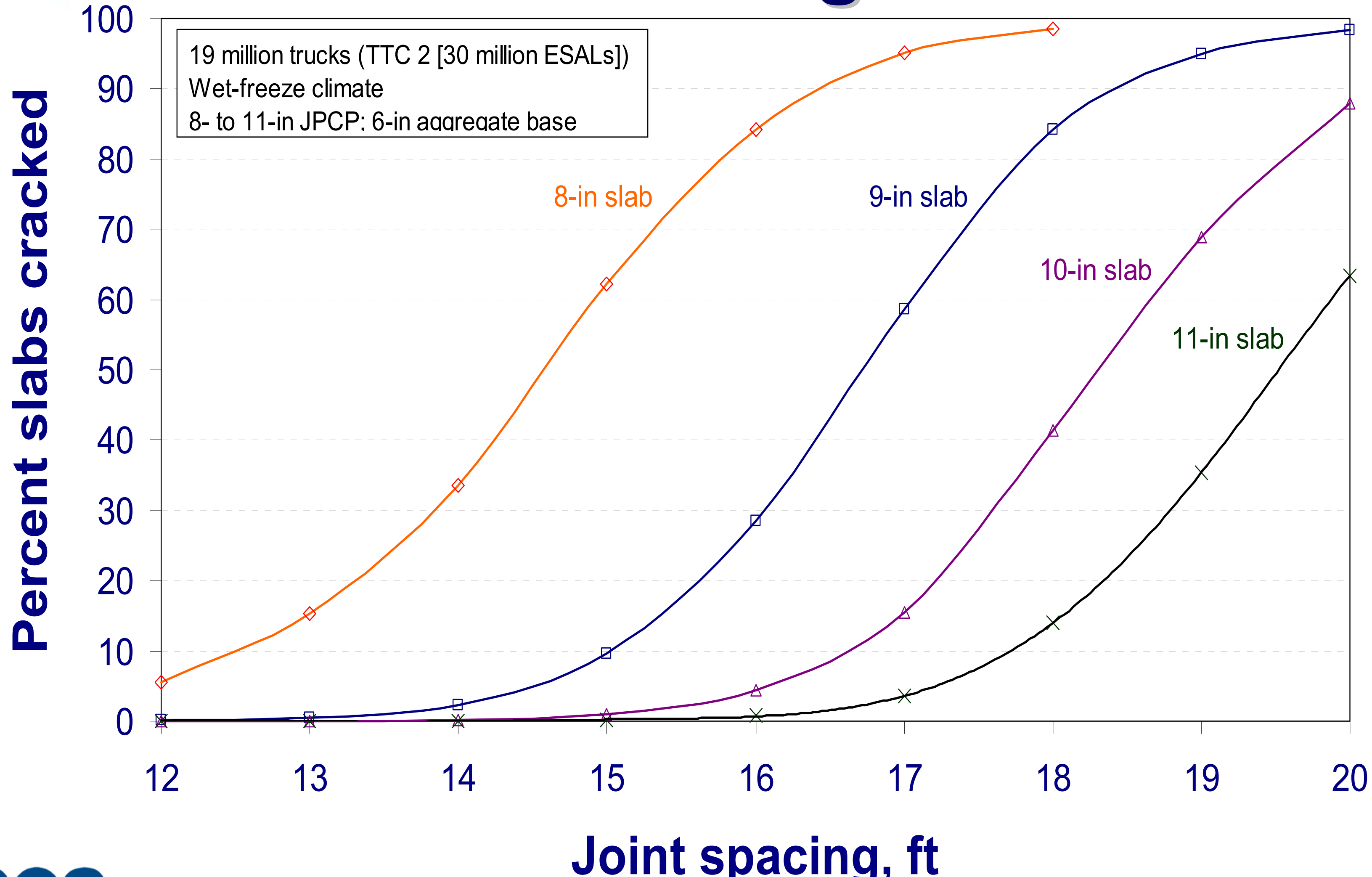
Concrete Coefficient of Thermal Expansion



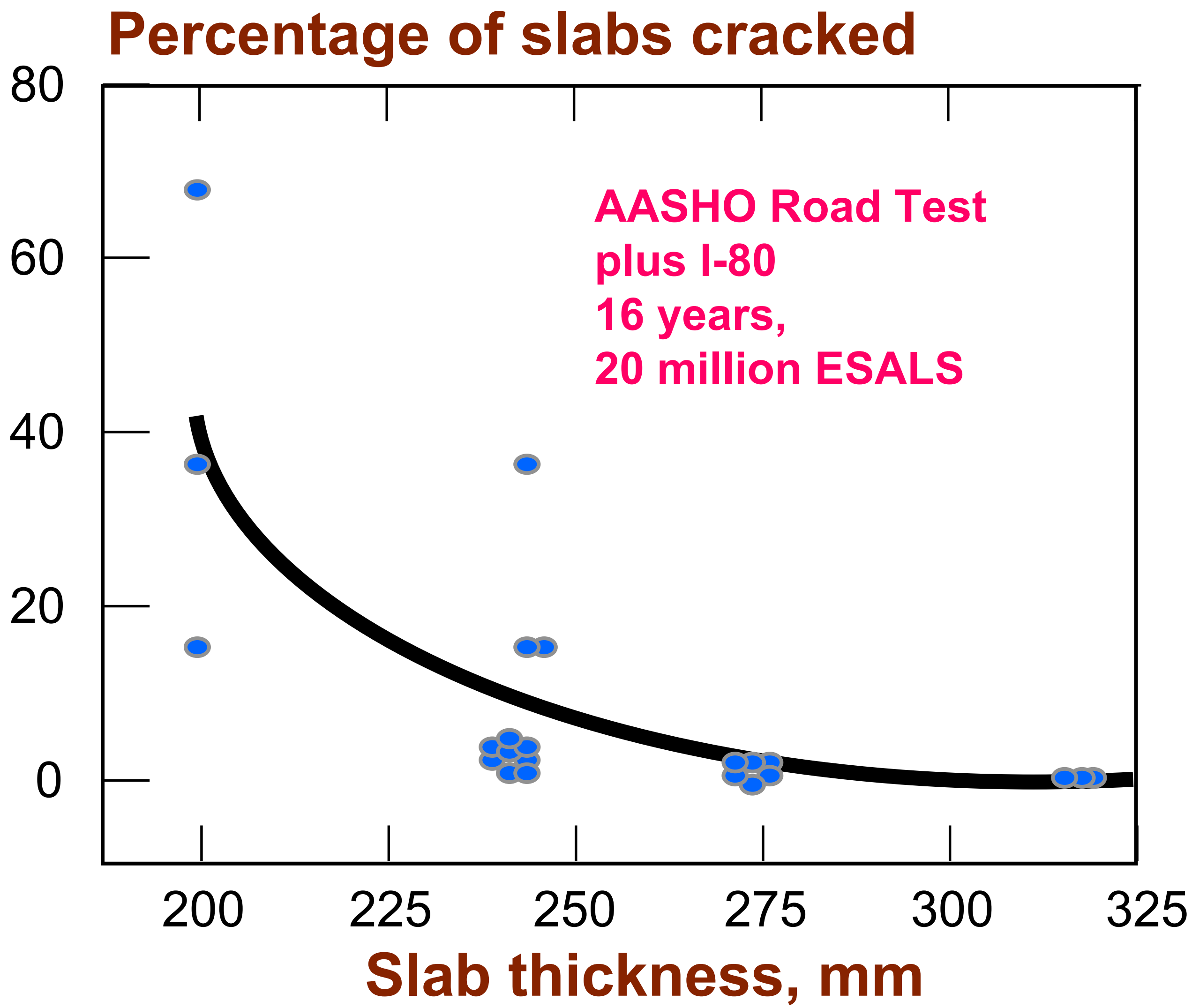
Slab Length Vs. Cracking



Slab Thickness & Joint Spacing Vs Cracking

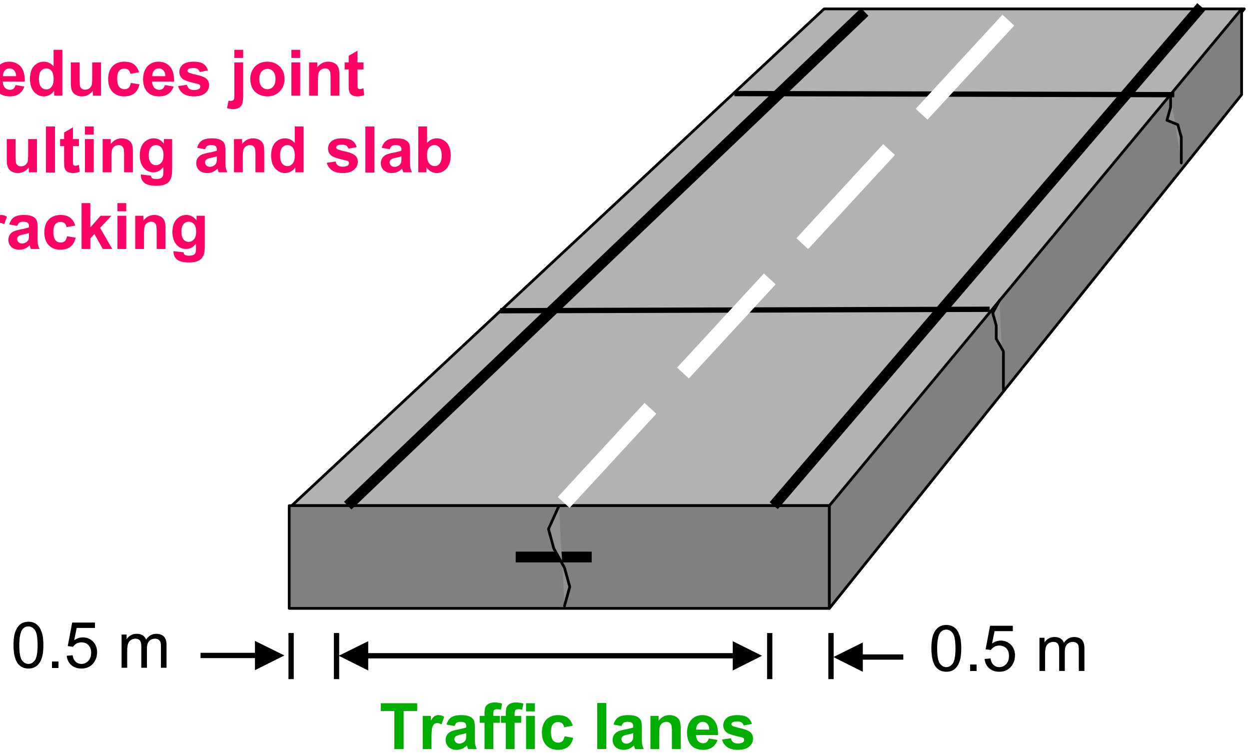


Slab Thickness Vs. Cracking

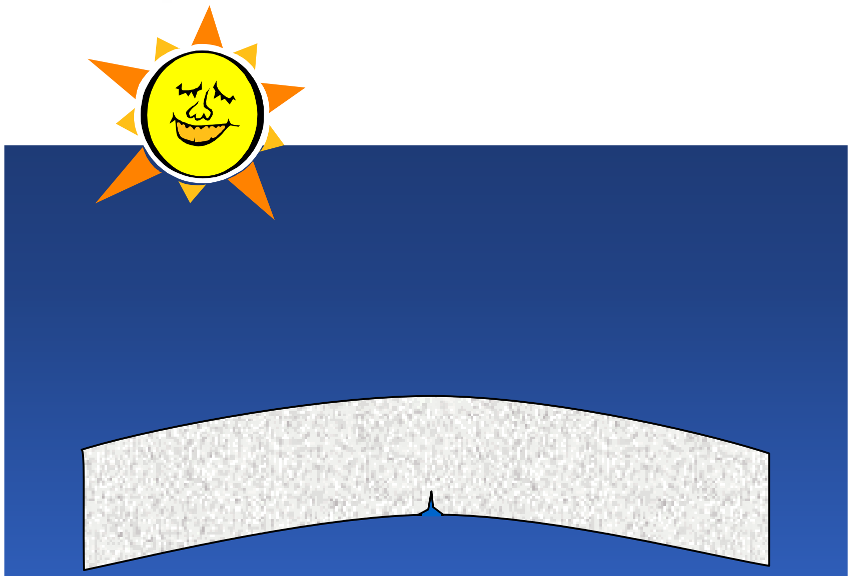


Widened Slab Design
(Cost Effective)

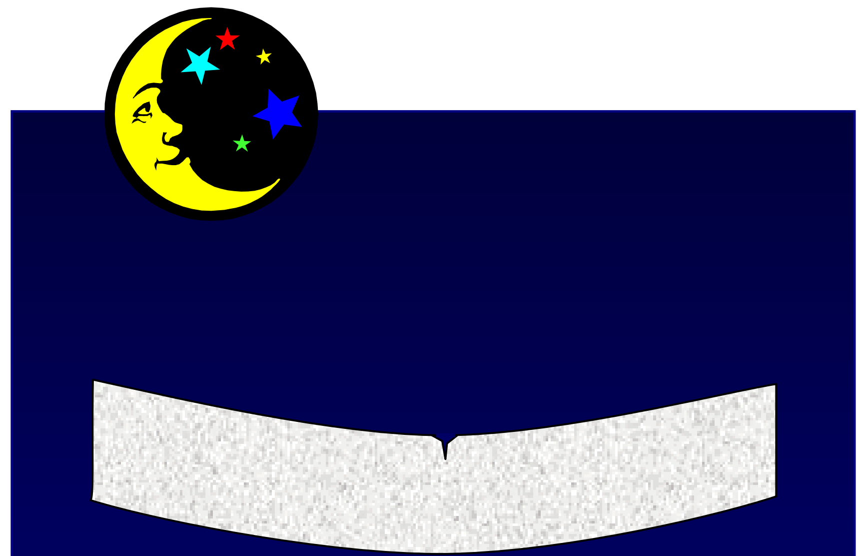
Reduces joint faulting and slab cracking



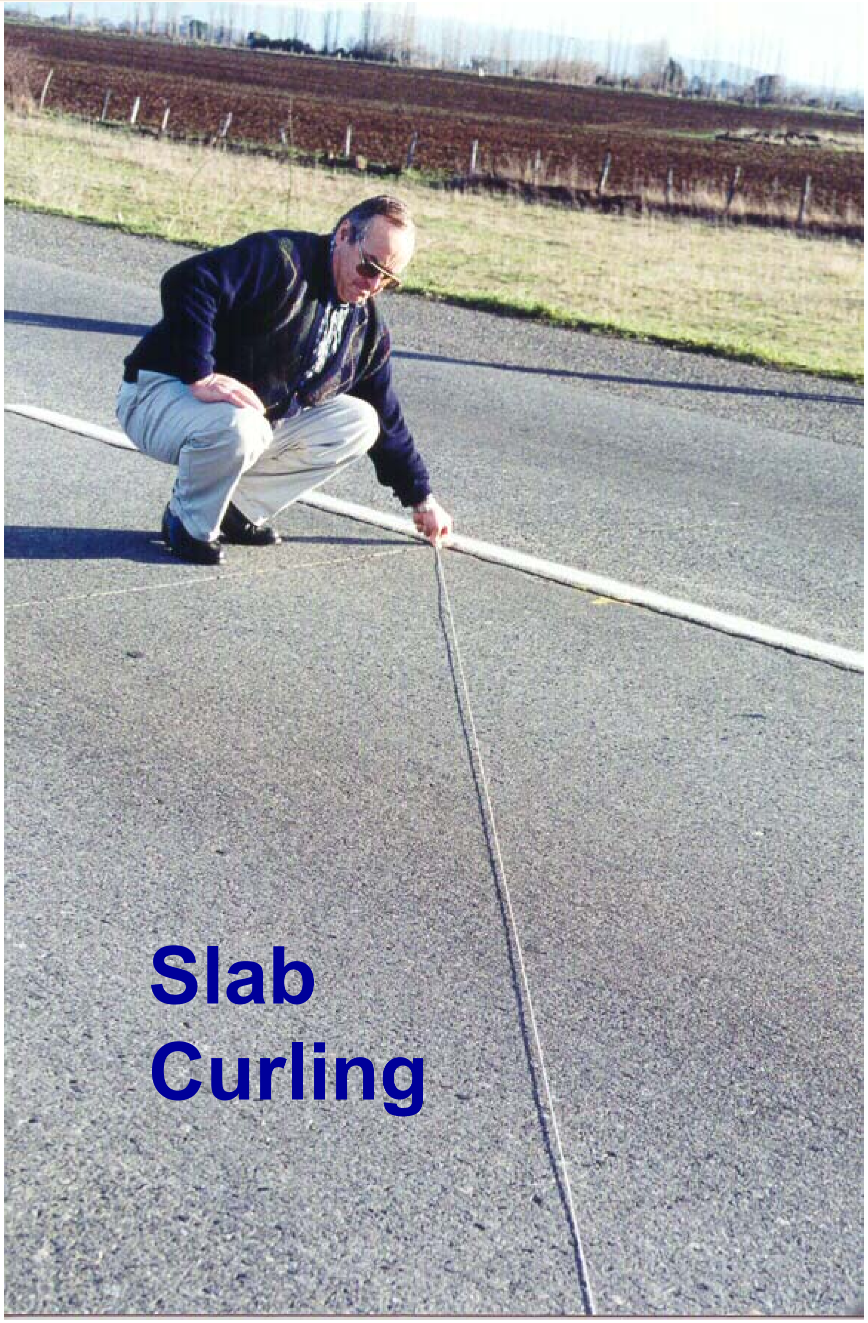
Climatic Factors
Slab Curling/Warping



Positive temp. gradient
Bottom Up Cracking

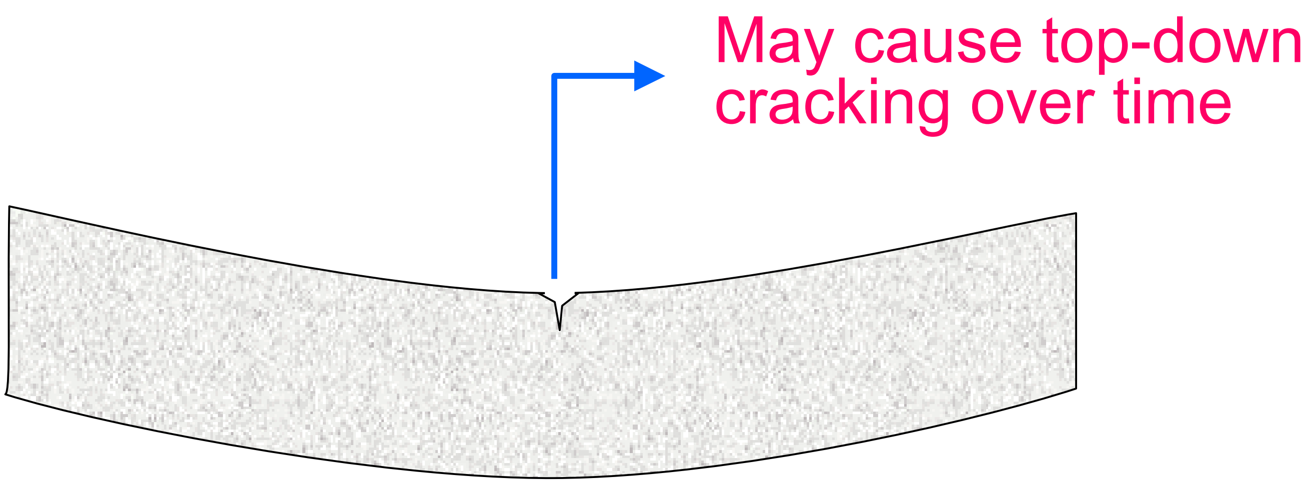


Negative temp. gradient
& shrinkage of surface
Top Down Cracking


Slab
Curling

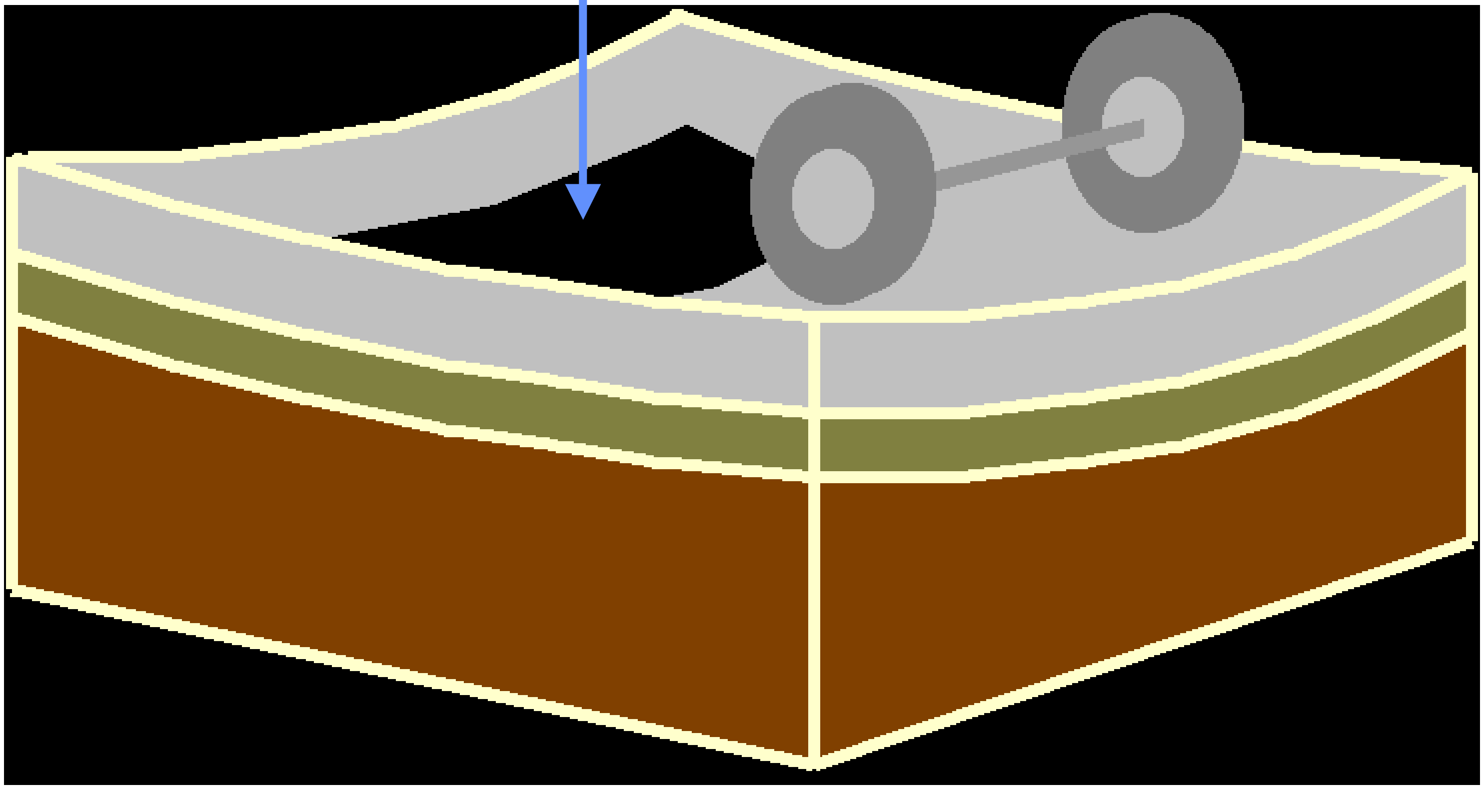
Construction Curling Problem

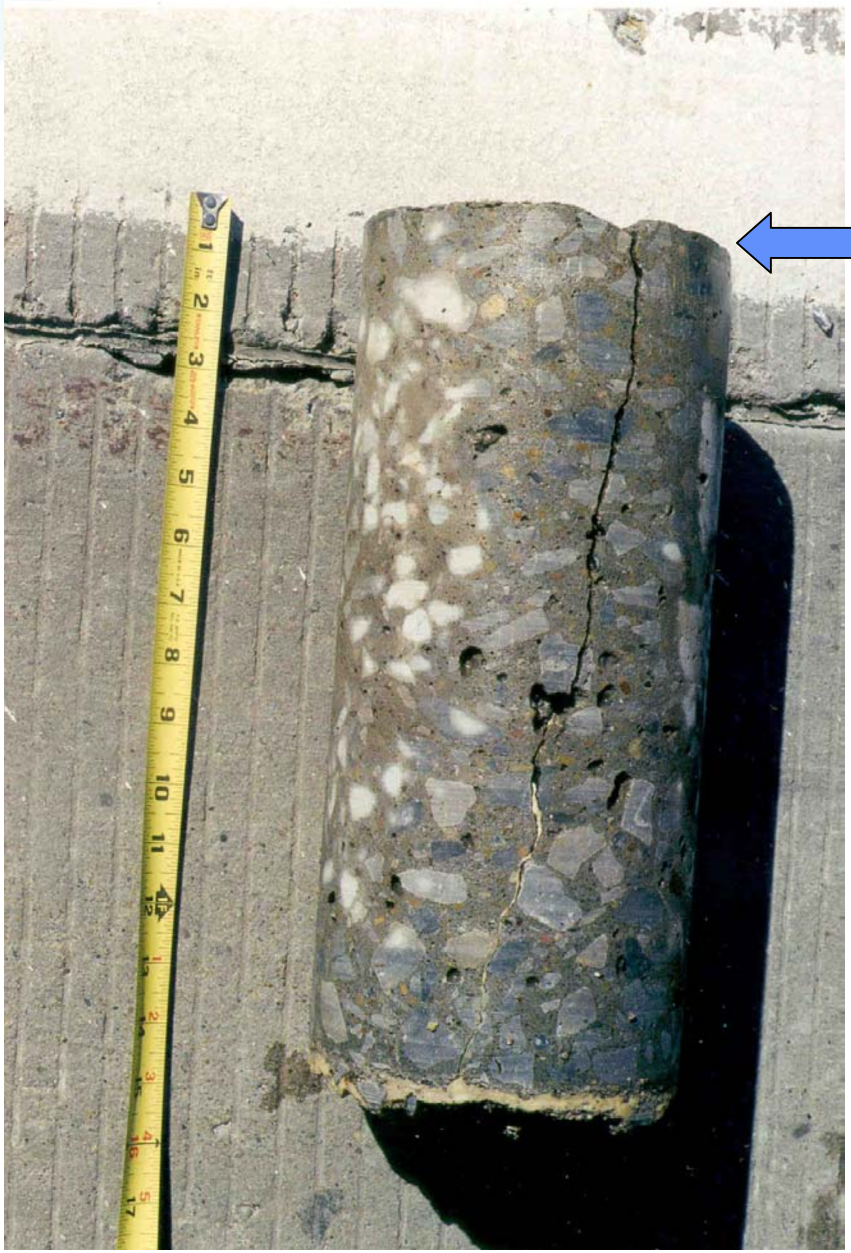
- Sunny, hot morning paving critical
- Negative temperature gradient built into slab results in upward curl over life



Upward Curl—Top Down Crack

Critical stress region
at top of slab



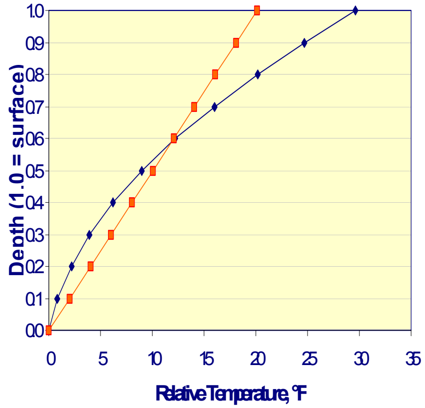


Top of slab
(crack initiation)

Expanding the Realm of Possibility

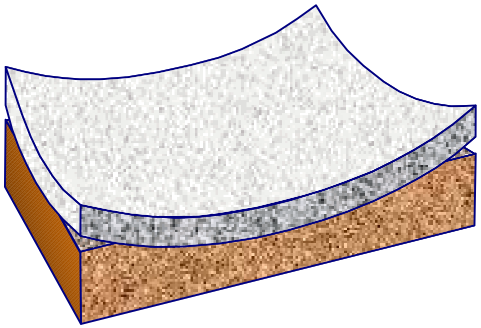
Now prevent through design & constr.

Components of Curl/Warp Stress (top down cracking risk)



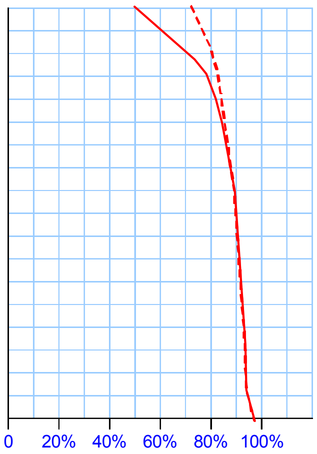
Actual Temperature Gradient

+



Built-in Curling

+

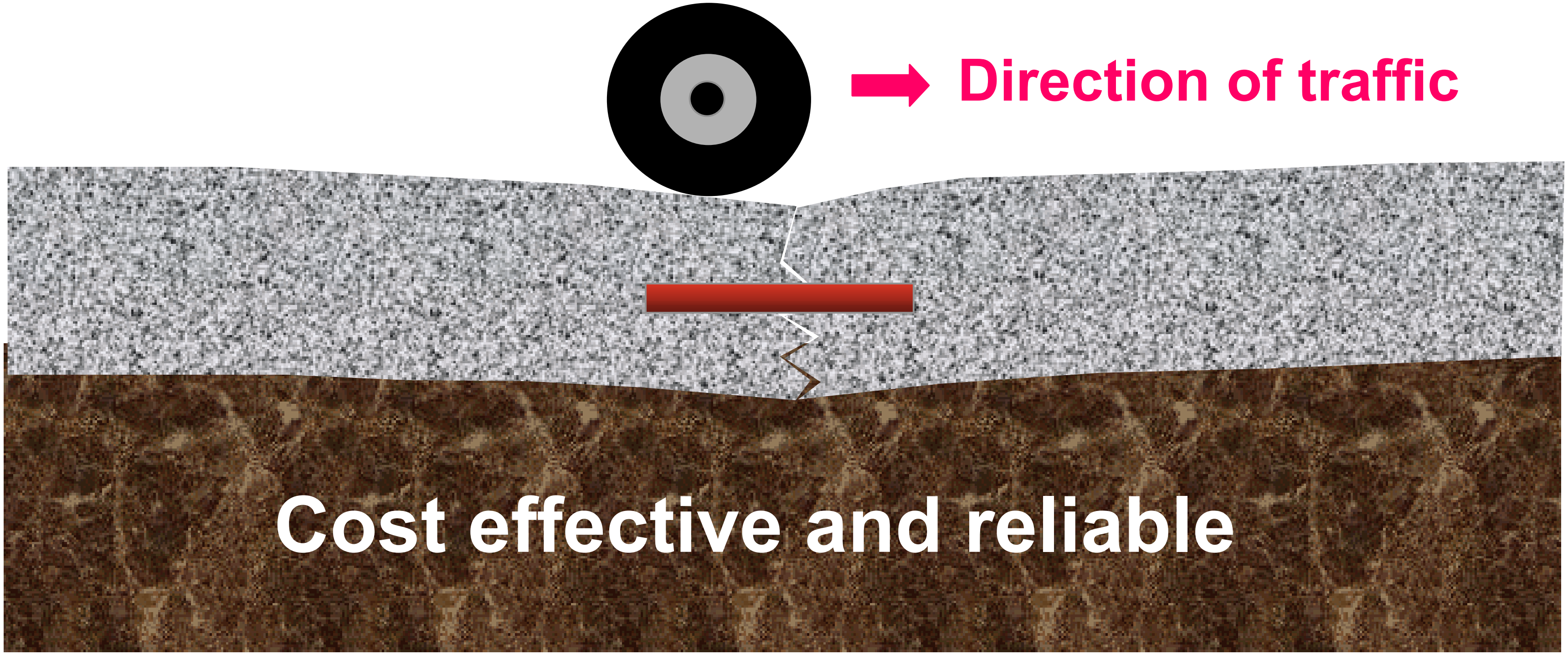


Moisture Gradient

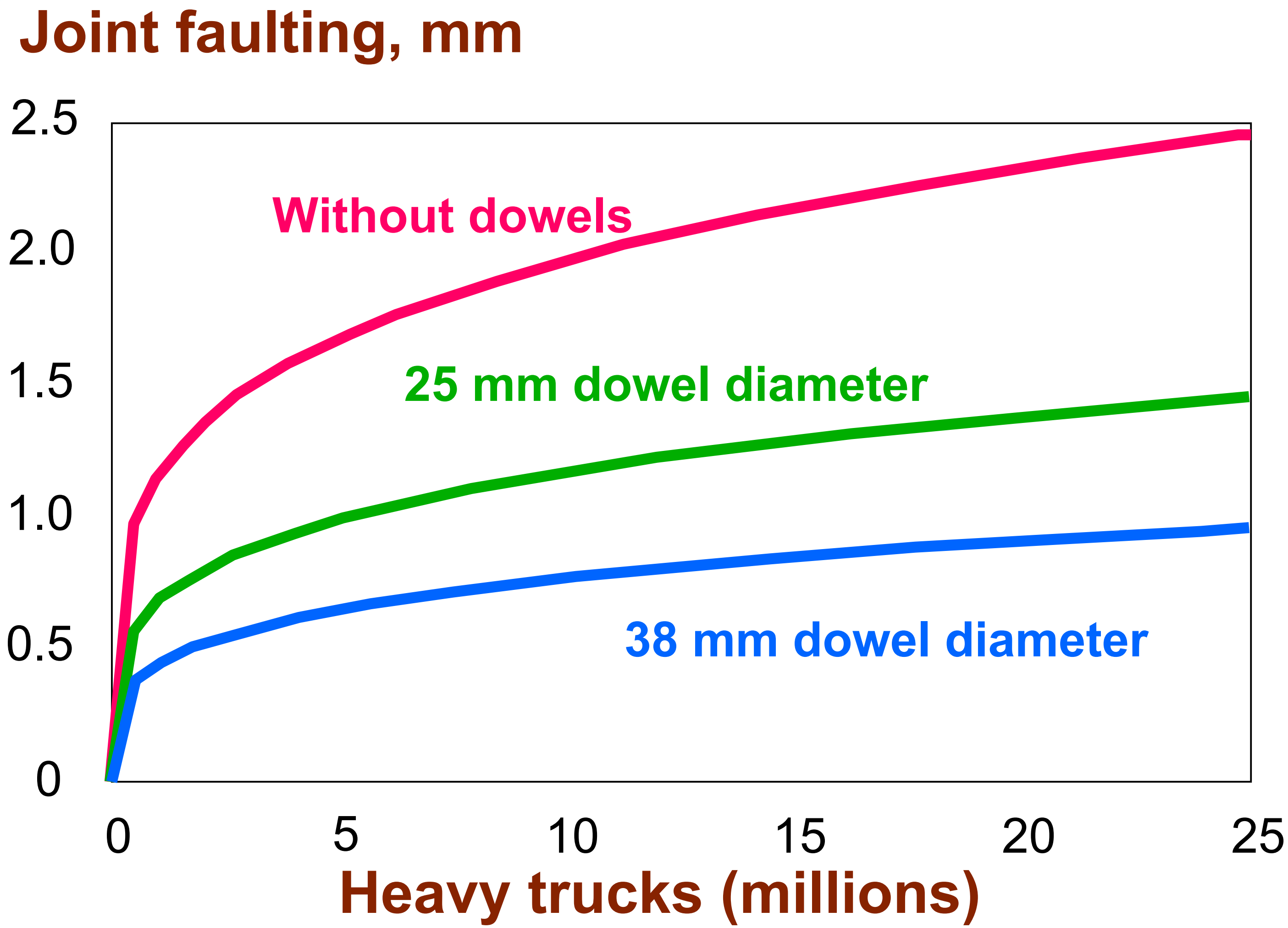
$$\Delta T = \Delta T_{Actual} + \Delta T_{Built-in} + \Delta T_{Shrinkage}$$

Joint Load Transfer

- Reduce deflections and stresses



Joint Performance



Build Concrete Pavement in Your Computer before Building in Field

- Select a trial design
- Obtain inputs, local climate, traffic, soils
- Run Design Guide Software year by year over design life
- Examine performance
- If problems, revise design

50-Year Design JPCP Example

- Project Interstate 405 Los Angles
- Widening of existing 8 to 12-lanes
- ADT 307,000, 5% trucks

50-Year Design JPCP — Results Traffic —

- Traffic loadings
  - ✓ Trucks: 126 million/lane/50 years
  - ✓ 4700/day/lane year 1
  - ✓ 9300/day/lane year 50

50-Year Design JPCP
— Trial Design —

- JPCP slab: 254 mm
- Joint spacing: 4.6 m
- Dowels: 38 mm diameter
- Base: Lean concrete
- Subbase: Aggregate
- Tied concrete shoulder

50-Year Design JPCP — Results 250 mm —

- **Joint faulting**: 0.8 mm **ok**
- **Slab cracking**: 11% at 50% Reliability
  - ✓ 25% at 95% Reliability **(too high)**
- **IRI**: 1.41 m/km **ok**

50-Year Design JPCP — Results 275 mm —

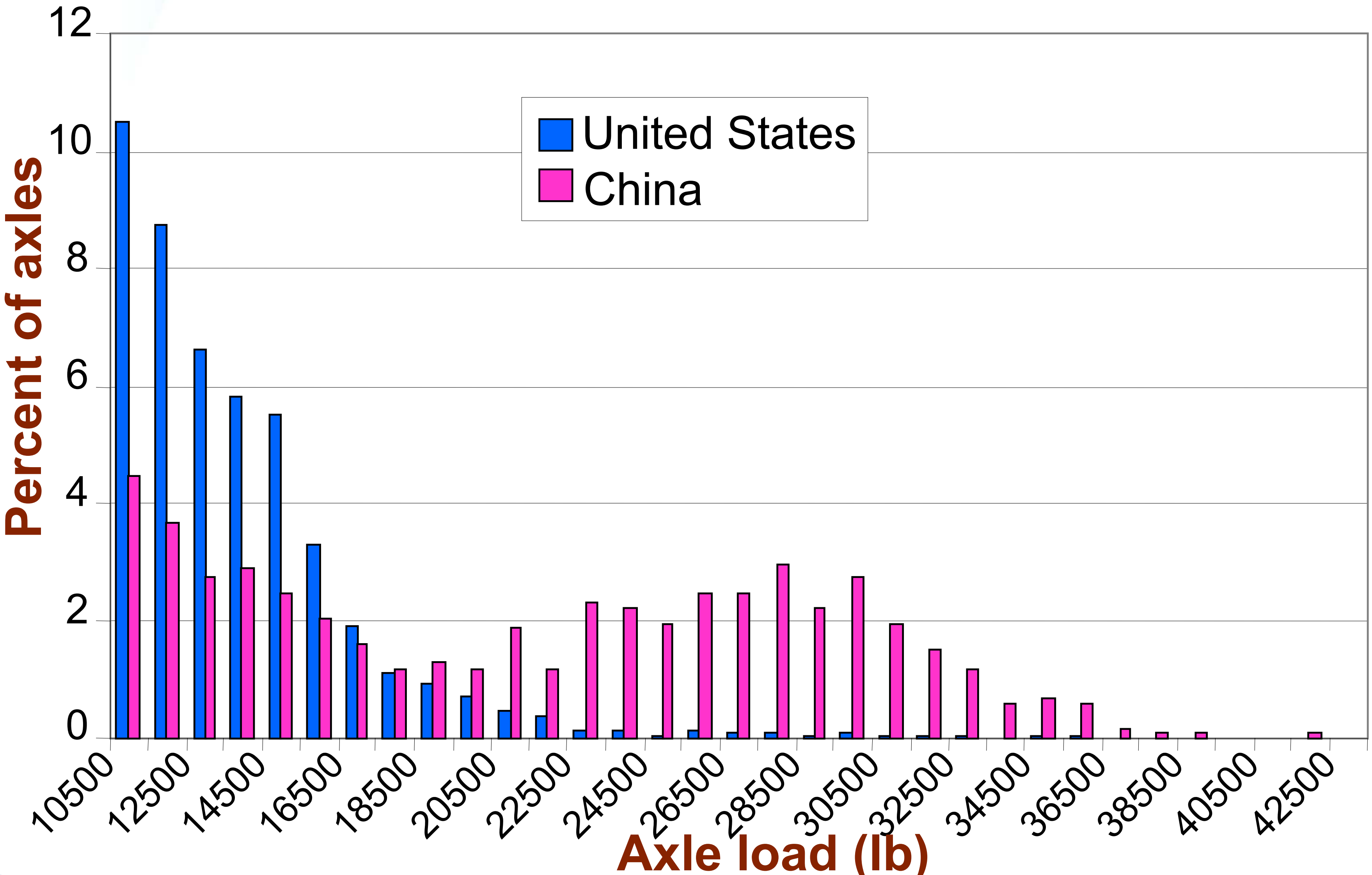
- **Joint faulting**: 0.7 mm **ok**
- **Slab cracking**: 3.5% at 50% Reliability
  - ✓ 13% at 95% Reliability **ok**
- **IRI**: 1.3 m/km **ok**
- **Acceptable Design**

The Future?

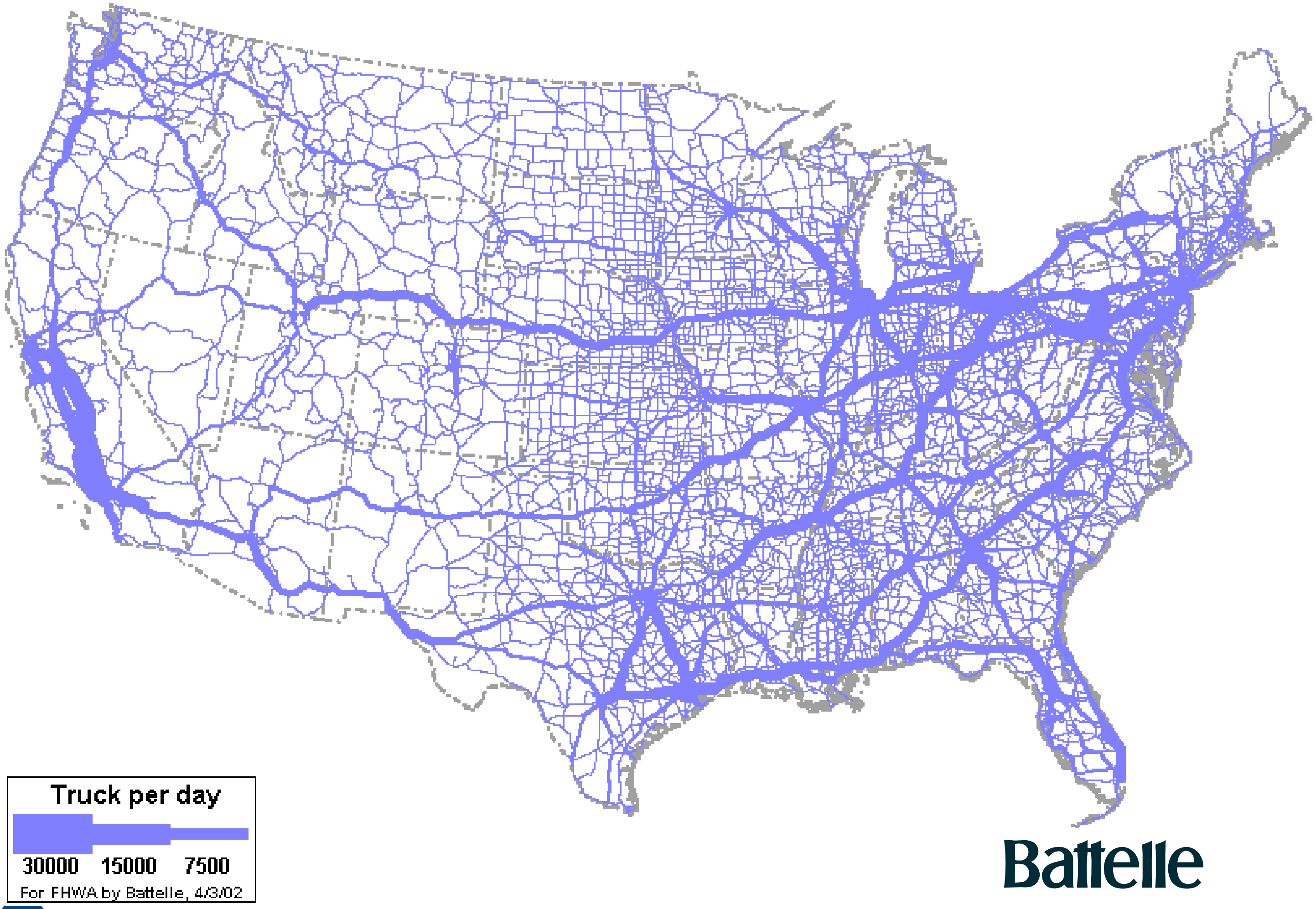
Traffic Loadings Axle Load Spectra

Single, Tandem, Tridem & Quad

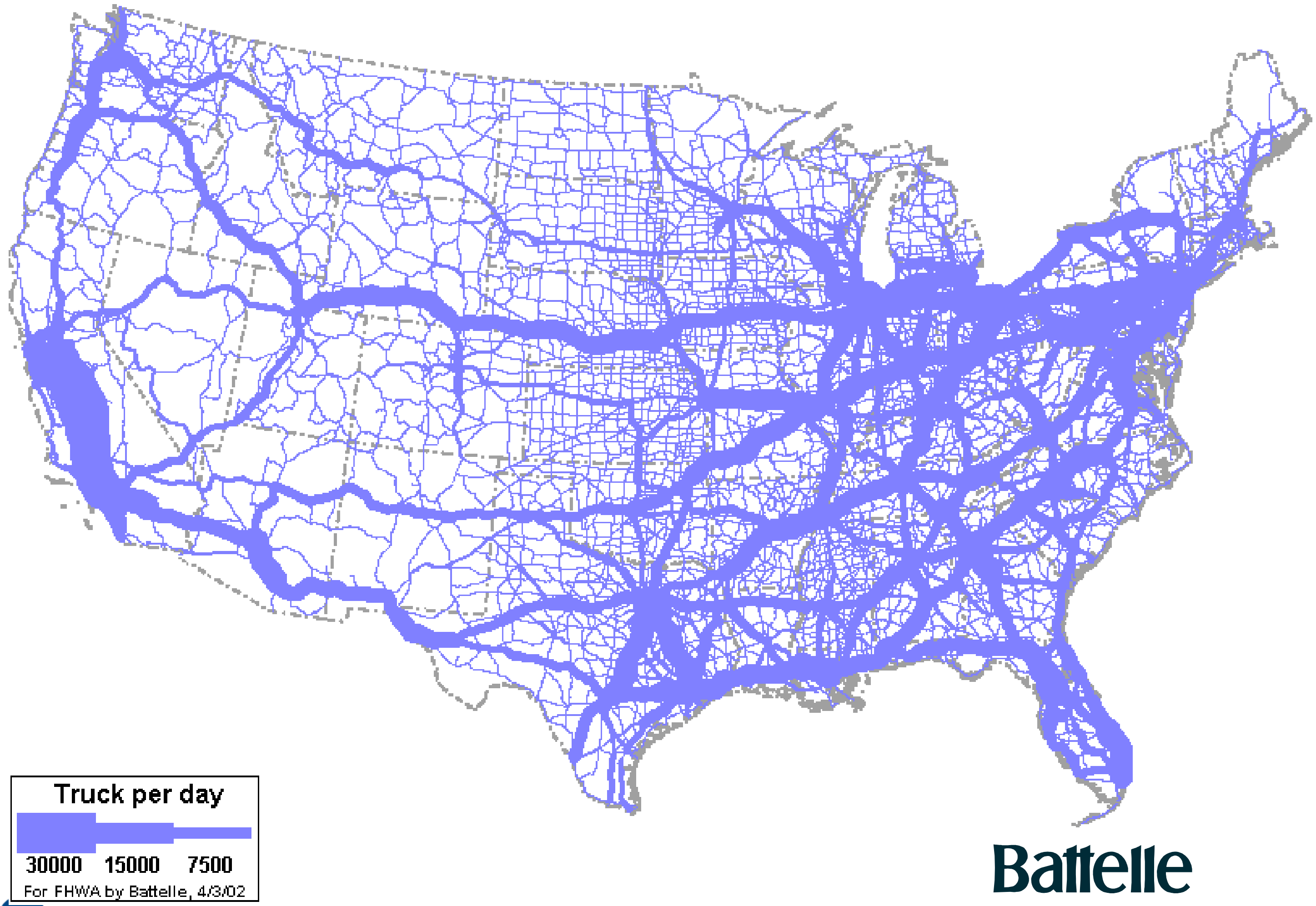
The Future: Heavier Axle Loads



1998 Truck Flow



2020 Forecast Truck Flow

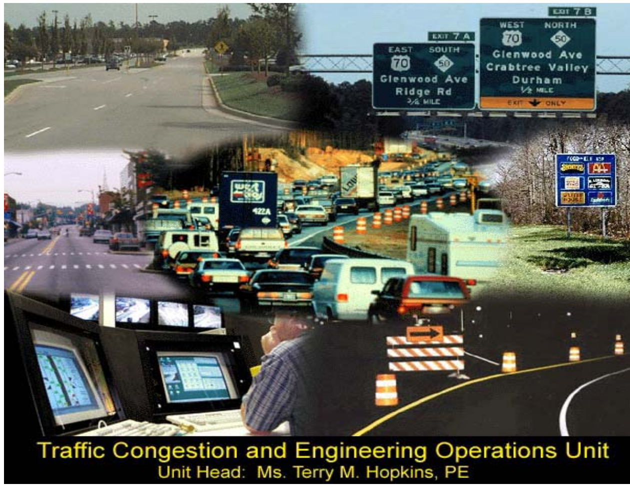


Battelle

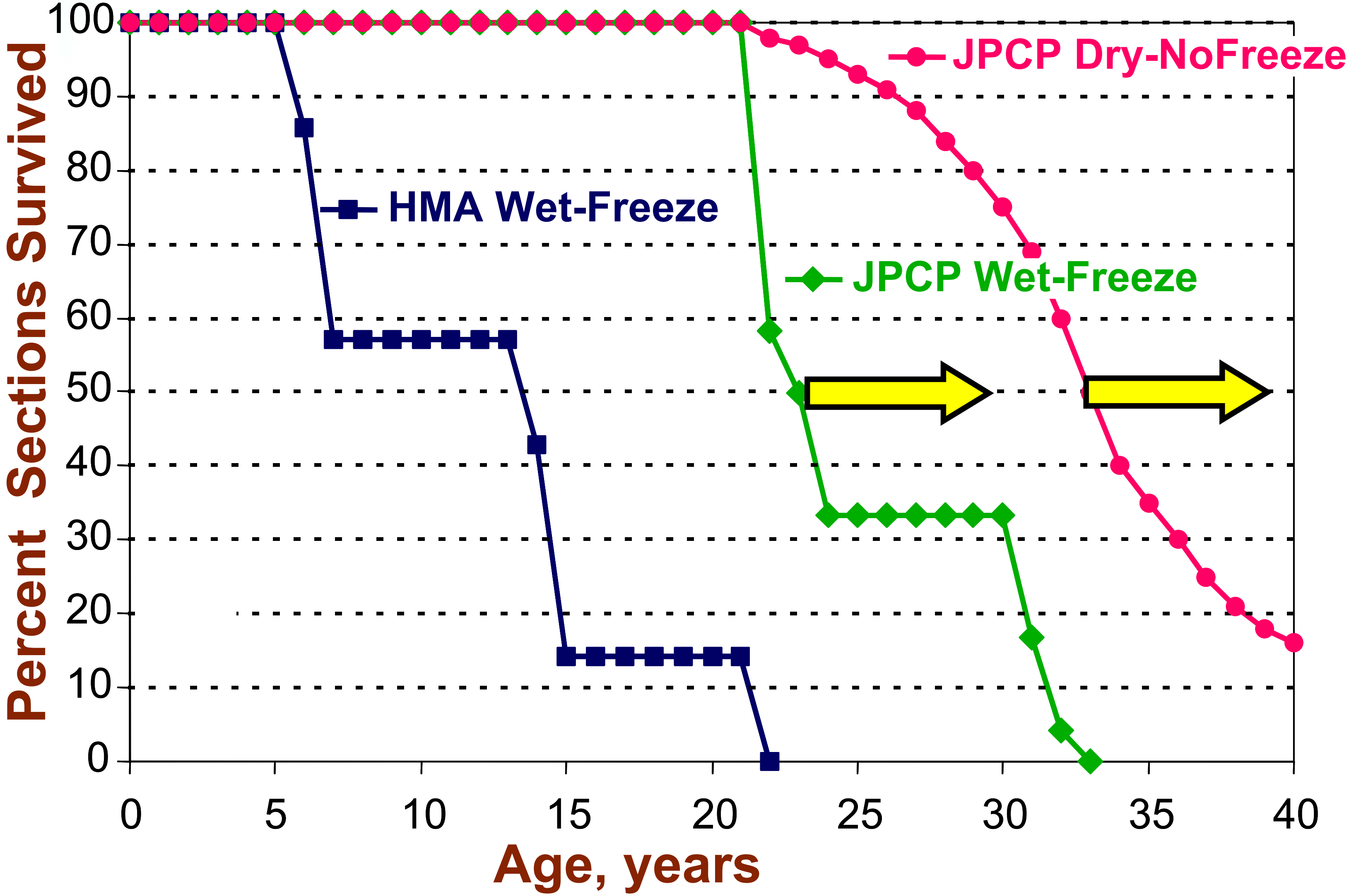
The Future

- Requirement for no lane closures for many, many years

- Rapid construction and maintenance required



The Future: Demand Longer Life



Thank you

Questions? emails welcome☺

mdarter@ara.com